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REPLACING THE WEIGHT OF MATERIALS CONSUMED ON AIRSHIPS.

By G. A. Crocco.

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REPLACING THE WEIGHT OF MATERIALS CONSUMED ON AIRSHIPS.*

By G. A. Crocco.

In a previous article** we showed that the gas lost in naviga-
tion, in an intensive airship traffic, may be a hundred-fold greater
than the loss by osmose; also that commercial aerial navigation,
with either helium or hydrogen, cannot enter into a practical phase,
until such loss is entirely eliminated.

It is hardly necessary to remark that the problem of replacing
the weight of the materials consumed becomes important only on long
trips, since, when the weight of the fuel consumed is only a small
fraction of the total lift, it may be offset dynamically by means
of the elevators. This is no longer possible, however, when the
weight of materials consumed on a long non-stop flight amounts to a
large share of the lift.

It then becomes necessary to provide other means, which are
practically reduced to two methods: condensing the water of combus-
tion and thermic sustentation. In the present article we will dis-
cuss the first method, leaving the second method to be examined in
a subsequent article.

Condensation of the water of combustion.- The light fuels used
on airships contain a high percentage of hydrogen, which, in burn-
ing, forms a large amount of water. On the average, 1000 g (2.2 lb)

of fuel contain 150 g (.33 lb) of hydrogen, corresponding to 1350 g (2.98 lb) of water vapor. Theoretically, therefore, it is possible to condense 1000 g, which would just replace the weight of the fuel consumed. The difficulties of this condensation depend on the temperature and humidity of the surrounding air, being greater in warm dry air and less in cold damp air.

If the air should be saturated with moisture on entering the engine, it would be possible to condense the requisite 1000 g of water at any temperature of intake. Conversely, it would also be possible, at low winter temperatures, for any degree of humidity. In ordinary navigation, especially intercontinental, the air is not always sufficiently cold or humid so that this method might present irregularities in the application of the theoretical principle which we will now illustrate.

Let us assume that P is the weight of air required for the combustion of 1000 g of gasoline and that the air had an initial temperature of t_0, a humidity of Φ_0 and pressure H_0. If F_0 is the tension of saturation corresponding to the temperature t_0, the volume of air corresponding to the weight P would be given by the formula

$$V = \frac{P\,(1 + \alpha t_0)}{1.7\,(H_0 - 0.377\,\Phi_0\,F_0)}\; ;$$

and the weight p_0 of the water vapor, contained in this volume, would be

$$p_c = 1.06\,\frac{\Phi_0\,F_0}{1 + \alpha t_0}\,V = \frac{0.623\,P}{\dfrac{H_0}{\Phi_0 F_0} - 0.377}\; ;$$

whence we may write, with sufficient approximation

(1) $$p_0 = 0.623 \ P \ \frac{\Phi_0 \ F_0}{H_0} \ .$$

To this weight there is added, during the combustion, 1350 g of water vapor. Consequently, by cooling the exhaust gases to the temperature t and the pressure H, they issue saturated with water vapor corresponding to the saturation tension F, carrying a weight of water vapor equal to about $0.623 \ P \times \frac{F}{H}$ and having deposited, during the cooling, a weight of water

(2) $$q = 1.35 - 0.623 \left(\frac{PF}{H} - \frac{P_0 \ \Phi_0 \ F_0}{H_0} \right),$$

from which, by practical calculations, we can write, with sufficient accuracy, $P = P_0$.

In order, therefore, to deposit a weight q of 1000 g, it is only necessary to have approximately the condition

(3) $$\frac{F}{H} = \frac{\Phi_0 \ F_0}{H_0} + \frac{0.56}{P_0}$$

which makes it possible to formulate the following theoretical principle:

Whatever the initial temperature and humidity of the air, there is always a definite ratio between the pressure of the exhaust gases and their tension of saturation, which solves the problem of causing the precipitation of as much water as the weight of the fuel burned. The present problem is to demonstrate that this ratio is practically realizable under ordinary meteorological conditions.

Naturally the temperature of the exhaust gases must be lowered

as much as possible. If, however, no other method were adopted for
reducing this temperature, other than that of cooling by means of
the surrounding air, the minimum limit of the temperature of the
gases would be that of the surrounding air, so that, in practice,
it would be a few degrees higher. We may therefore write

$$t \equiv t_0 + \tau$$

The effect of τ is deduced from the following table, in which
we have assumed $P_0 \doteq 22$ kg (48.5 lb) and $\Phi_0 = 0.5$ and entered
the values, expressed in meters of water, of the pressure necessary
to obtain $q = 1000$.

Temperature of surrounding air, $t_0=$	Pressure increases in meters of water for $\Phi_0 = 0.5$ and for			
	$\tau \equiv 2^0$	$\tau = 4^0$	$\tau = 6^0$	$\tau = 8^0$
20^0	0	0	0	0.12
25^0	0	0	0.73	1.98
30^0	0.47	0.72	3.11	4.62

From these values it may be seen how difficult it is for τ to
exceed 5^0, which we will take as the average in the following calcu-
lations. In practice the determination of τ depends on the nature
of the cooling surfaces, as we will set forth in a later communica-
tion.

By varying the humidity of the air, we obtained the results
given in the following table.

Temperature of surrounding air. t_O =	Pressure increases in meters of water for $\tau = 5^O$ and for		
	$\Phi_O = 0.25$	$\Phi_O = 0.5$	$\Phi_O = 0.75$
20°	0.05	0	0
25°	2.59	0.19	0
30°	5.33	1.87	0.83

From these data it is seen that the increases in pressure are not at all negligible, when the air is very warm and dry. Fortunately, this combination is very rare.

A careful investigation of the meteorological conditions in various parts of the globe* has demonstrated that, as a general rule, the absolute humidity of the air increases at the same rate as the temperature, that is, Φ_O undergoes few and exceptional variations. We found in Italy an average relative humidity of about 60%, with a minimum of 50 and a maximum of 80; in the Azores, between 68 and 84%; at Rio de Janeiro, between 70 and 85%; while only over arid lands have relative humidities been found as low as 33% combined with temperatures above 30^OC. Only on exceptional occasions would we have to do with temperatures above 30° and relative humidities below 50%.

It may be noted that the absolute humidity decreases with the altitude, this being offset, however, by a decrease in temperature, so that high altitudes are generally advantageous for the condensation of water vapor from the exhaust gases. Hence we have limited our calculations to $H_O = 760$.

* Use was made of the abundant data of Prof. Eredia of the Meteorological Observatory of Rome.

Lastly, it should be noted that the higher temperatures are encountered for only a portion of the day and of the year and that, in intensive aerial navigation, the important thing is the annual saving in the consumption of materials. Consequently, figures which may appear important when considered for a short trip, become negligible as regards the whole year's traffic.

For these reasons and especially the last one, devices may be considered acceptable from the practical point of view, even though designed to function partially and having but very little effect on the annual consumption, provided, on the other hand, they make it possible to secure, in every instance, the restoration of the weight lost by the consumption of fuel.

We will indicate, nevertheless, how the required pressure may be further reduced, for the purpose of completing the theory in all its bearings.

It is necessary, however, to go further in cooling the exhaust gases, by utilizing the pressure itself, by means of adiabatic expansion with eventual recovery of power. The temperature decreases, thus rendered possible, will be utilized, with suitable exchange of temperature, for the further cooling of the gases and the consequent condensation of the water vapor, so that a lower pressure will suffice than that indicated in the preceding tables.

In order to indicate approximately the magnitude of this new pressure, we will assume that the exchange of heat is complete between the cold gases and the gases to be cooled. Designating the temperature fall due to expansion by Δt; the new minimum tempera-

ture of the gases before expansion by t_1; the final exit temperature by t_2; their specific heat by c; we will have the equation:

$$606.5 (1 - q) + c P_0 (t_0 + \tau - t_1) = c P_0 (t_2 - (t_1 - \Delta t))$$

in which q is derived from equation (2), by substituting the new values of F and H. This equation may be simplified by the allowable assumption that $t_2 = t_0$, thus becoming

$$c P_0 (\Delta t - \tau) = 606.5 (1 - q)$$

which can be solved graphically, by taking the pressures $H - H_0$ as abscissas and by taking as ordinates the quantities of heat corresponding to the temperature decreases $\Delta t - \tau$, on the one hand, and to the weights of the condensed vapor $1 - q$ on the other.

The reduced pressures thus obtained are given in the following table.

Temperature of surrounding air $t_0 =$	Pressure increases in meters of water, by the expansion method, for	
	$\Phi = 0.25$	$\Phi = 0.50$
25°	1.74	-
30°	3.15	1.45

In order to decide on the practical utility of the expansion method, it is now necessary to determine the power required to produce the increase in pressure. This may be done in two ways: either by constricting the exhaust, so as to produce a counterpressure in the engine, or by compressing the gases with a separate compressor, after cooling.

The first method is simpler, since no special mechanism is re-

quired, but only a reduction in the size of the outlet. This method, however, consumes more power.

The second method harmonizes with the theoretical principle, assuming it to be the difference between the work of compression and that of expansion, and requires a smaller expenditure of power. This difference may be determined by joining to the same shaft both a turbo-compressor and turbo-engine. The turbo-compressor receives and compresses the gases already cooled and then passes them on to be expanded in the turbo-engine after cooling, direct or indirect, by the external atmosphere and then by the gases which have already undergone adiabatic cooling. Hence, by assuming an efficiency of about 60% for both mechanisms, the practical work d of compression is reduced to the theoretical. The power required for the increased compression is then shown by the following table.

Increased compression in meters of water.	Increased power in % required by Method of counterpressure.	Separate compression.
1	2.87	1.5
2	5.75	3.0
3	8.60	4.3
4	11.90	5.5

The larger powers would only be necessary for short portions of the voyages and a small number of days in the year, so that the increased annual consumption would seldom exceed one percent. This makes preferable (except in especially hot and dry climates) the method of counterpressure in the engine, which presents no mechanical complications.

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